

FY 2005 Interim Project Report

RFID-Assisted Localization and Communication for First Responders

L. E. Miller, N. P. Bryner, P. F. Wilson, M. H. Francis, J. R. Guerrieri,
D. W. Stroup, and L. Klein-Berndt

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1. Introduction

In this introductory section, we describe the project, state the concepts that have motivated the study, and summarize the technical approach for the project work.

1.1 *Project Description*

RFID (radio-frequency identification) devices commonly are attached to persons or to moveable objects so that the objects can be tracked using fixed readers (special-purpose radios) at different locations. In this project, supported by the NIST Advanced Technology Program (ATP), we propose to explore a novel application of the “flip side” of this practice based on the concept that detection of an RFID device in a known, fixed location by a moving reader provides a precise indication of location for tracking the person or moving object that is carrying the reader. The research will evaluate the exploitation of this concept to implement a low-cost, reliable means for tracking firefighters and other first responders inside buildings, where navigation using GPS is not reliable—indeed, the GPS signal may have been disabled temporarily to prevent exploitation by terrorists [1]. The research will also consider the use of building-related information stored in RFID devices placed at fixed on-site locations to aid the responders in their mission, as well as to describe the room layout or other context of the device, thereby minimizing the need for accessing remote databases through the communication system.

Previously, ATP has funded research and development of a wireless network by Time Domain, Inc. and GE Corporate Research and Development [2] that integrates communications, precise tracking, and data telemetry, based on ultrawideband (UWB) technology, for use in hospital and manufacturing environments. The system envisioned by this proposal is intended for an environment that is potentially much less “friendly” to RF propagation—the in-building environment of first responders that may contain smoke, dust, or flames—and is intended to leverage advances in ubiquitous RFID tag technology, in combination with recent advances in miniaturized inertial sensors, to develop a low-cost tracking system that does not depend upon the stability of the RF environment over relatively large distances to derive range from precision timing. The “philosophy” of the proposed RFID-assisted system also involves reducing the dependence on RF links to external data sources by exploiting the capability of RFID tags to store critical building information for retrieval when it is needed, where it is needed.

1.2 *Concepts motivating the study*

1.2.1 Indoor Navigation Cannot Depend on GPS

As mentioned above, it cannot be assumed that GPS position solutions will be available to first responders in a mission-critical situation. Even without the prospect of having the GPS signals blocked or obscured for tactical advantage, the reception of GPS signals inside most buildings is not reliable.

1.2.2 Inertial Sensors Can Track Location, Motion

In addition to, or in place of, GPS the position of a first responder inside a building can be tracked using inertial sensors such as accelerometers and gyroscopes. Non-inertial sensors such as magnetometers and barometers can also be used in conjunction with dead reckoning methods to develop positions of a first responder in motion.

1.2.3 RFID Fixes Can Enhance the Accuracy of Inertial Tracking Systems

Inertial tracking systems inherently drift over time and produce errors in position, especially for inexpensive and lightweight systems. Corrections to the position solution at points along the path of the first responder can limit the maximum error to an acceptable level. Corrections, in the form of the insertion of known locations that have been reached, can be entered manually or they can be developed automatically by the detection of an RFID device, either by correlating the identity of the device with a table of locations or by reading the device's location from data stored on it.

1.3 Approach to the study

1.3.1 Overall Approach

At the outset of the study, the overall approach was described as follows:

In addition to assessing the RF (radio frequency) propagation environment of buildings in emergency situations, the research will consider several operational scenarios consisting of (1) the strategy for RFID deployment, (2) the tracking method, and (3) the options for presenting location information to the user and communicating this information to a monitoring station. The RFID deployment and tracking aspects of the scenarios to be studied will include:

- The tradeoffs involved in the choice of RFID devices for this application, including cost, ease of programming, suitability for emergency environments, and data capacity.
- Use of relatively few RFID location reference points to correct or calibrate an inertial navigation or other localization system to maintain sufficient accuracy during a first responder incident.
- Use of multiple RFID location reference points to furnish data for tracking without the use of inertial sensors.

The emphasis will be to make maximum use of information and to leverage software to simplify hardware implementations. The presentation and communication aspects of the scenarios to be studied will include:

- Informing the user (only) of position (stand-alone mode), assuming any communication is provided by a separate system.
- Informing the user, other team members, and an incident commander of their positions via an ad hoc network of radio terminals that combine RFID reading and radio communication.

- Providing the user with directions for safe exiting of the building.

The results of the research will include documentation of the feasibility analyses, protocol development and tests, establishment of a demonstration/test building environment, and prototype/ demonstration hardware in the form of reader-radio terminals using ad hoc networking protocols and localization software.

1.3.2 Related Projects

The [Wireless Communication Technologies Group](#) (WCTG) of the [Advanced Network Technology Division](#) (892/ANTD) of NIST's [Information Technology Laboratory](#) (ITL) has had a number of projects relating to wireless ad hoc networks [3] and to indoor localization. The efforts described by this report are for the most part complementary in that a very different scheme for localization is envisioned than those studied previously. However, many of the ad hoc networking concepts are similar to those used in prior work on public safety localization and communication applications [4].

The [Radio-Frequency Fields Group](#) of the [Electromagnetics Division](#) (818/ED) of NIST's [Electronics and Electrical Engineering Laboratory](#) (EEEL) carries out antenna and electromagnetic (EM) compatibility measurements providing a national metrology base for the characterization of the EM properties of components, materials, systems, and environments throughout the radio spectrum.

The Fire Fighting Technology Group of the [Fire Research Division](#) (866/FRD) of NIST's [Building and Fire Research Laboratory](#) (BFRL) develops and applies technology, measurements and standards, and improves the understanding of the behavior, prevention and control of fires to enhance fire fighting operations and equipment, fire suppression, fire investigations, and disaster response. Research is being conducted in areas of fire fighter localization, intelligent building systems, firefighter training, and structural collapse prediction to improve emergency responder situational awareness. This project complements other work on ad hoc networking and fire-fighter communications.

1.4 Project Milestones and Plans

1.4.1 Milestones

The original ATP proposal milestones are itemized below and also summarized in Table 1.1 in a way that highlights the collaboration among the project participants and the intended outcomes from the study.

1.4.1.1 FY 2005 Milestones

- A. Define critical parameters of firefighter localization and in-building informational requirements in typical scenarios that relate to the building RF propagation environment and to the number and placement of RFID tags in buildings, as well as the type of data to be stored on the tags. (BFRL, EEEL)
- A. Evaluate inertial and dead-reckoning navigation techniques and device options (including MEMS-based sensors) regarding their accuracy, availability, and

suitability for integration with an RFID reader on a small platform for location updating. (ITL)

- B. Analyze the requirements for the number of RFID tags and their placement to achieve desired localization accuracies, as a function of navigation techniques and device options. (BFRL, ITL)
- C. Evaluate options for RFID technologies—including both tags and readers—to use for location updating of a navigation system implemented on a small, battery-powered device similar to a handheld computer or PDA (personal digital assistant). (EEEL, ITL)
- D. Establish a project web page. (ITL)¹
- E. Document/publish interim results. (ITL, EEEL, BFRL)

1.4.1.2 FY 2006 Milestones

- A. Select RFID tag and reader technologies and develop a prototype reader for use in this application. (EEEL)
- B. Develop embedded software for acquisition of data from the RFID reader and use of that data to perform location updates and to display the location on a handheld computer as well as building information derived from RFID tag data. (ITL, EEEL)
- C. Conduct preliminary experiments in NIST's Large Fire Facility to evaluate the performance of RFID-assisted localization devices in structures of simple geometry. (BFRL)
- D. Evaluate options for interfacing the localization device with an ad hoc wireless communication network (ITL, BFRL)
- E. Document/publish interim results. (ITL, EEEL, BFRL)

1.4.1.3 FY 2007 Milestones

- A. Develop embedded software for interfacing an RFID-assisted localization device with an ad hoc wireless communication network. (ITL, BFRL)
- B. Integrate RFID reader, navigation hardware and software, and ad hoc communication system for prototype testing. (EEEL, ITL)
- C. Identify test sites/buildings and conduct tests to demonstrate the operation of the prototype localization and communication system in burning or smoke-filled building environments. (BFRL, ITL)
- D. Develop embedded software for directing the user to the nearest RFID-tagged exit. (ITL)
- E. Document/publish final results. (ITL, EEEL, BFRL)

¹ The project web page is found at <http://www.antd.nist.gov/wctg/RFID/RFIDassist.htm> and also is reproduced in the Appendix as seen online.

Table 1.1 Summary of Project Milestones

Task helper →	ITL	EEEL	BFRL
Task leader ↓	FY 2005		
ITL	Evaluate inertial and dead-reckoning navigation techniques and device options regarding their accuracy, availability, and suitability for integration with an RFID reader on a small platform for location updating. Establish a project web page. Document/publish interim results.		
EEEL	Evaluate options for RFID technologies—tags and readers—to use for location updating of a navigation system implemented on a small, battery-powered device similar to a handheld computer or PDA (personal digital assistant).	Document/publish interim results.	
BFRL	Analyze the requirements for the number of RFID tags and their placement to achieve desired localization accuracies, as a function of navigation techniques and device options.	Define critical parameters of firefighter localization and in-building informational requirements in typical scenarios that relate to the building RF propagation environment and to the number and placement of RFID tags in buildings, as well as the type of data to be stored on the tags.	Document/publish interim results.
	FY 2006		
ITL	Document/publish interim results.	Develop embedded software for acquisition of data from the RFID reader and use of that data to perform location updates and to display the location on a handheld computer as well as building information derived from RFID tag data.	Evaluate options for interfacing the localization device with an ad hoc wireless communication network.
EEEL		Select RFID tag and reader technologies and develop a prototype reader for use in this application. Document/publish interim results.	
BFRL			Conduct preliminary experiments in NIST's Large Fire Facility to evaluate the performance of RFID-assisted localization devices in structures of simple geometry. Document/publish interim results.
	FY 2007		
ITL	Develop embedded software for directing the user to the nearest RFID-tagged exit. Document/publish final results.		Develop embedded software for interfacing an RFID-assisted localization device with an ad hoc wireless communication network.
EEEL	Integrate RFID reader, navigation hardware and software, and ad hoc communication system for prototype testing.	Document/publish final results.	
BFRL	Identify test sites/buildings and conduct tests to demonstrate the operation of the prototype localization and communication system in burning or smoke-filled building environments.		Document/publish final results.

1.4.2 Outline of This Report

Following this introduction, the report contains four main sections and a section containing reference material.

Section 2 summarizes the scope and the progress and findings for FY 2005 Milestone A, concerning the critical parameters of firefighter localization and in-building informational requirements.

Section 3 summarizes the scope and the progress and findings for FY 2005 Milestone B, concerning the evaluation of inertial and dead-reckoning navigation techniques.

Section 4 summarizes the scope and the progress and findings for FY 2005 Milestone C, concerning the requirements for number and placement of RFID tags.

Section 5 summarizes the scope and the progress and findings for FY 2005 Milestone D, concerning the options for RFID technologies.

Section 6 contains references cited in the report.

The appendix reproduces the project web page as seen online.

2. FY 2005 Milestone A: Firefighter Localization Parameters

2.1 Scope of Tasks

2.1.1 Restatement of Milestone A

Define critical parameters of firefighter localization and in-building informational requirements in typical scenarios that relate to the building RF propagation environment and to the number and placement of RFID tags in buildings, as well as the type of data to be stored on the tags.

2.1.2 Scope

Conceptually, this milestone has two major questions to answer:

- What should an indoor localization/communication system *do* for the first responders? That is, how should it function and what are the measures of success for its functionality?
 - For example, does the individual in the building need to know (outside of the exiting emergency) the information being communicated outside the building?
 - For example, what quantities in addition to location should be measured, and how frequently, how precisely, etc.?
- How does the indoor scenario/environment affect the operation of RFID tag reading and, consequently, the strategy for deploying the tags?
 - For example, if the tags are on every door because they provide information on what's in the rooms, perhaps an inertial or other tracking system isn't needed.
 - Another example: what, if any, conventions/standards exist for describing locations within buildings? Is there a coordinate system² that is suitable for any arbitrary building?
 - Is the operation of an RFID device affected by the temperature and air characteristics of the building in an emergency situation?

The scope of these questions is very broad, so it was realized early in this first year of the project that it was only possible to *begin* answering these questions.

2.2 Progress and Findings

2.2.1 Summary of Progress

In response to the questions posed above, firefighter location and in-building information requirements have been developed, as representing perhaps the most demanding environment for

² See the stairway indexing system at
<http://www.arlingtonva.us/Departments/Fire/prevention/FirePreventionStairway.aspx>

an RFID-assisted localization and communication system. The implications for placement of tags have been identified as the survival of the functioning of the tag in the environment.³ The number of RFID tags is still an open question, depending on a tradeoff between practicality and the desired localization resolution—in many first responder scenarios, it would be a much-needed advancement to be able to identify which room in a building a given first responder is located. This question will continue to be considered in later phases of the project.

2.2.2 Summary of Findings

Firefighter location and in-building information requirements may be grouped in terms of (a) building type, (b) temperature environment, (c) radio attenuation factors, and (d) desired location resolution.

Building type refers both to the building's construction, which relates to its resistance to fire, and to factors affecting communications in the building. The building type, along with classification of the building use (*e.g.*, residential or industrial), is the primary parameter in the description of the fire event scenario. Building and fire codes classify buildings according to the type of construction and the fire resistance of the various load-bearing and non load-bearing elements, such as exterior and interior walls, columns, beams and girders, and floor construction. There are five types of building construction identified in the various codes [5, 6]:

- *Type I Buildings* are classified as Fire-Resistive. Most of these buildings are used as high-rise office buildings, shopping centers, or residential units. They will be either reinforced concrete or structural steel. Structural members will be approved noncombustible or limited-combustible materials with specified fire resistance ratings. Any steel construction members must be protected to withstand prescribed test temperatures for fire resistance.
- *Type II Buildings* are classified as Noncombustible. These buildings can be used for example as office buildings, warehouses, or automobile repair shops. There are three basic types of non-combustible buildings: metal frame covered by metal exterior walls (Butler Buildings), metal frame enclosed by masonry as non-bearing exterior walls, and masonry bearing walls supporting a metal roof. These metal roofs can be either solid steel girders and beams, or lightweight open-web bar joists or a combination of both with corrugated metal sheathing. The structural members are noncombustible or limited-combustible materials.
- *Type III Buildings* are classified as Ordinary. Type III buildings are often called ordinary buildings or combustible/noncombustible. The majority of buildings probably fall into the Type III category. These buildings can be office buildings, retail stores, mixed occupancy, dwellings, or apartment buildings. These buildings usually have non-combustible bearing walls and combustible roofs. Usually, the exterior walls are concrete, concrete block, or brick. Interior, non-load bearing walls can be made of wood.
- *Type IV Buildings* are classified as Heavy Timber. The exterior and interior walls and structural members that are portions of walls must be of approved non-combustible or limited combustible materials. Interior structural members, including walls, columns, floors, and roofs, are large dimension solid or laminated wood timbers. The exterior walls are typically masonry. These buildings exist primarily in the New England area.

³ High temperature testing of the functionality of typical RFID tag systems will be conducted in FY 2006, using FY 2005 DHS funds that have been made available in part on an interest in this ATP project.

- *Type V Buildings* are classified as Wood Frame. Wood frame buildings generally are constructed in one of five methods: log, post and beam, balloon, platform, and plank and beam. A wood frame building can be used for many different purposes, such as single-family dwellings, multiple-family dwellings, restaurants, or retail stores. The major structural members are typically composed of wood and the exterior walls are combustible.

The communications factors associated with the building type include whether the building has a pre-wired communication system and whether the construction of the building is such that radio signals may not penetrate the building adequately (*e.g.*, steel or metal).

The temperature environment of a building during a first responder event is described in terms of zones that correspond to degrees of exposure to heat flux and therefore to risk of injury [7]. The following tables give examples of fires in the different temperature and heat flux zones.

Table 2.1 Examples of Zone I environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [8]	None		
Abeles Project Fires, 1980 [9]	Class 1	Overhaul, up to 30 minutes	Temperature to 40 °C Flux to 0.5 kW/m ²
IAFF Based on Abeles Project Fires 1980	Class 1	Overhaul, up to 30 minutes	Temperature to 40 °C Flux to 0.5 kW/m ²
FRDG, FEU 1995 [10]	Routine	Elevated temperature, no direct thermal radiation, 25 minutes	Temperature to 100 °C Flux to 1.0 kW/m ²
Coletta, 1976 [7]	None		
Abbott, 1976 [11]	None		

Table 2.2 Examples of Zone II environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [8]	Routine	One or two objects burning	Temperature 20 °C to 60 °C Flux 1.0 to 2.1 kW/m ²
Abeles Project Fires, 1980 [9]	Class 2	Small fire in a room, 15 minutes	Temperature 40 °C to 95 °C Flux 0.5 to 1.0 kW/m ²
IAFF Based on Abeles Project Fires 1980	Class 2	Small fire in a room, 15 minutes	Temperature 40 °C to 93 °C Flux 0.5 to 1.0 kW/m ²
FRDG, FEU 1995 [10]	Hazardous	Elevated temperature and direct thermal radiation, 10 minutes	Temp. 100 °C to 160 °C Flux 1.0 to 4.0 kW/m ²
Coletta 1976 [7]	Routine	Fighting fires from a distance	Temperature to 60 °C Flux 0.4 to 1.25 kW/m ²
Abbott 1976 [11]	Routine	Fighting fires from a distance	Temperature to 70 °C Flux 0.5 to 1.7 kW/m ²

Table 2.3 Examples of Zone III environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [8]	Ordinary	Serious fire, next to a room in flashover; 10 to 20 minutes maximum	Temp. 60 °C to 300 °C Flux 2.1 to 25 kW/m ²
Abeles Project Fires, 1980 [9]	Class 3	Totally involved fire, 5 minutes	Temp. 95 °C to 250 °C Flux 1.0 to 1.75 kW/m ²
IAFF Based on Abeles Project Fires, 1980	Class 3	Totally involved fire, 5 minutes	Temp. 93 °C to 260 °C Flux 1.0 to 1.75 kW/m ²
FRDG, FEU 1995 [10]	Extreme	Rescue, retreat from flashover or backdraft	Temp. 160 °C to 235 °C Flux 4.0 to 10.0 kW/m ²
Coletta 1976 [7]	Hazardous	Outside burning room or small building	Temp. 60 °C to 300 °C Flux 1.25 to 8.3 kW/m ²
Abbott 1976 [11]	Ordinary	Outside burning room or small building	Temp. 70 °C to 300 °C Flux 1.7 to 12.5 kW/m ²

Table 2.4 Examples of Zone IV environments.

Group, Year	Designation	Description	Ranges
USFA, FEMA 1992 [8]	Emergency	Severe and unusual, 15 to 30 seconds for escape	Temp. 300 °C to 1000 °C Flux 25 to 125 kW/m ²
Abeles Project Fires, 1980 [9]	Class 4	Flashover or backdraft, up to 10 seconds	Temp. 250 °C to 815 °C Flux 1.75 to 42 kW/m ²
IAFF Based on Abeles Project Fires, 1980	Class 4	Flashover or backdraft, up to 10 seconds	Temp. 260 °C to 815 °C Flux 1.75 to 42 kW/m ²
FRDG, FEU 1995 [10]	Critical	Could be encountered briefly	Temp. 235 °C to 1000 °C Flux 10 to 100 kW/m ²
Coletta 1976 [7]	Emergency	Not normally encountered, may be during flashover	Temp. 300 °C to 1000 °C Flux 8.3 to 105 kW/m ²
Abbott 1976 [11]	Emergency	Not normally encountered, may be during flashover	Temp. 300 °C to 1100 °C Flux 12.5 to 208 kW/m ²

Radio attenuation factors are those affecting the transmission of radio signals into and out of a burning building. These factors include

- Presence of water in the air, due either to combustion products or the fire suppression water. 100% relative humidity can be expected.
- Smoke particulates in the air, usually carbon. Typically one gram per cubic meter.
- Charged particles in the air that are ions from combustion processes.
- Thermal layers that could reflect or refract radio waves.
- Construction materials and their various attenuation properties. Adverse effects can be from the metal facing on insulation, metal rebar in concrete, metal siding, and solar window treatments.

The desired resolution of indoor location information during a first responder event varies according to the scenario, that is, whether the building is residential or industrial. The following tables correlate the location resolution in meters to the accuracy in locating personnel and escape openings.

Table 2.5 Location parameters for residential scenarios.

Resolution in meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	City Block +/-	10 floors +/-		
10	Front or rear of house	3 floors +/-	Structure +/- (Townhouse)	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

Table 2.6 Location parameters for industrial scenarios.

Resolution in meters	Location		Escape	
	X-Y Direction	Z Direction	X-Y Direction	Z Direction
100	Building +/-	10 floors +/-		
10	Section of Bldg	3 floors +/-	Section of Bldg	Floor +/-
1	Room	Floor +/-	Correct Wall	Window or Door
0.1	Location in Room	Correct Floor	Location on wall	Height of window or door

3. FY 2005 Milestone B: Navigation Techniques and Devices

3.1 Scope of Tasks

3.1.1 Restatement of Milestone B

Evaluate inertial and dead-reckoning navigation techniques and device options (including MEMS-based sensors) regarding their accuracy, availability, and suitability for integration with an RFID reader on a small platform for location updating.

3.1.2 Scope

During project discussions, it was agreed that, conceptually, this milestone has two major components:

- Survey and evaluation of navigation techniques
 - Special interest in indoor navigation
 - Special interest in low cost and simplicity
- Survey and evaluation of inertial navigation sensor technology
 - Special interest in low cost, low power, and small size
 - Include recent “pedestrian navigation” solutions

3.2 Progress and Findings

3.2.1 Summary of Progress

- The survey and evaluation of navigation techniques has been completed, with the major findings summarized below.
- The survey and evaluation of inertial navigation sensor technology has been completed, with the major findings summarized below.
- On the basis of the surveys, a particular dead-reckoning module (DRM) has been selected for testing, and a sample of the module is on order (using Division funds).
- A report containing survey details and tutorial materials on navigation has been drafted; its completion awaits testing of the selected DRM so that the test results may be included.

3.2.2 Summary of Findings

The most widely used navigation system today is the Global Positioning System (GPS), which enables position determination through the measurement of time delays of signals from multiple satellites in known (moving) positions; the time delay measurements are based on cross-correlating received satellite signals with local replicas to identify the signals’ digital code position in time relative to the common reference. The difficulty in using GPS indoors and in urban “canyons” is that the line of sight to the GPS satellites is obscured or severely attenuated. Without four good satellite signals, the GPS position solution is inaccurate. Also, with weak

signals, the GPS receiver continually loses lock and must spend an inordinate amount of time in attempting to acquire the signals.

Prior to the establishment of GPS, of course, many techniques and devices for navigation have been used. Today's navigation devices implement some very old navigation techniques, such as dead reckoning and waypoint navigation. Dead Reckoning (DR) is the process of estimating your position by advancing a known position using course, speed, time and distance to be traveled—in other words, figuring out where you will be at a certain time if you hold the speed, time and course you plan to travel [12]. The usefulness of the technique depends upon how accurately speed and course can be maintained on a given “tack,” in the air and on the sea, the selection of fixed speed and course for relatively long periods of time are feasible, while on land or inside buildings the duration of the tack may need to be relatively short due to maneuvers that are required by the terrain or building layout. As illustrated in Figure 3.1, the uncertainty of the DR position grows with time, so that it is necessary to check the position regularly with a “fix” of some kind (perhaps an RFID tag as envisioned by this project).

Various systems are being proposed for “pedestrian navigation” utilizing DR techniques and small compasses. For example, [14] describes a small DR unit that utilizes a two-axis compass, a three-axis compass, or a rate gyroscope to track a walking person's heading. The heading produced by the 3-axis sensor is least affected by deviations in the person's orientation—very important in the case of first responders, who often do not walk “normally” in the course of their work. For computation of speed (actually, displacement as a function of time), the system in [14] uses an accelerometer to detect the person's steps; on average, the distance covered by a step was found to be quite consistent, even though the detection process can be rather subtle:

A greater understanding of the movements and forces was required and a more detailed analysis of the motion of the feet was carried out. Also, since every step is independent of any other then we believed that it would be possible to realise an improvement over the systems that employ step frequency analysis as a means of deducing current speed across the ground. This event driven approach could also prove valuable in analysing disjointed steps that occur when altering course and changing speed.... An important point is that when humans stride further, apart from just stretching out the legs further, the feet move faster for stability reasons.... Hence, it is postulated that the acceleration of the foot (in the vertical plane rather than in the direction of motion) is greater when the foot makes a larger stride. It is this hypothesis that allows us to deduce that the greater the vertical acceleration of the foot during a step, the greater the distance that was traveled across the ground. This is a relationship that we can exploit to enable us to adjust the pedestrian's pre-calculated stride and hence reduce the error associated with a fixed stride.

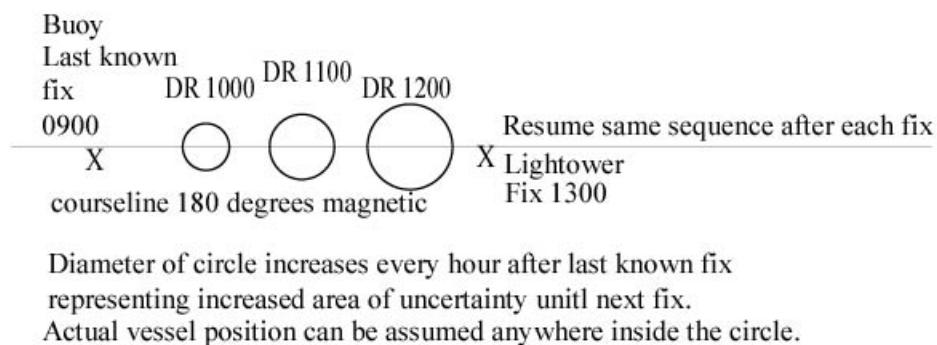


Figure 3.1 Dead reckoning with open ocean (from [13]).

Another observation is that humans rarely under-step their minimum average stride again for stability reasons...except for when they are turning on the spot which does not affect distance across the ground). In using this stride length scaling technique based on step energy we can analyse the variations in the raw acceleration data rather than rely on noise intolerant integration techniques.

The performance of the system in [14] with a 2-axis magnetic compass and step detection using an accelerometer in an urban “tourist area” test is shown in Figure 3.2 in comparison to GPS. The scales in the figure are in meters. Although the DR positions were generally in agreement with those developed by GPS, they were often significantly different, due in part to unknown magnetic effects along the path, probably from the presence of an underground electric utility substation along the path. The standard deviation of the position area for the test was about 20 m. The authors conclude, “This case illustrates the susceptibility of magnetic compasses to localized magnetic fields, particularly in an urban environment. In these circumstances a gyroscope solution is clearly advisable.”

Another personal navigation product based on dead reckoning and step counting is the Point Research Corporation’s⁴ Dead Reckoning Module (DRM), which integrates a GPS receiver with a magnetic compass and other sensors [15–17] and is described as follows:

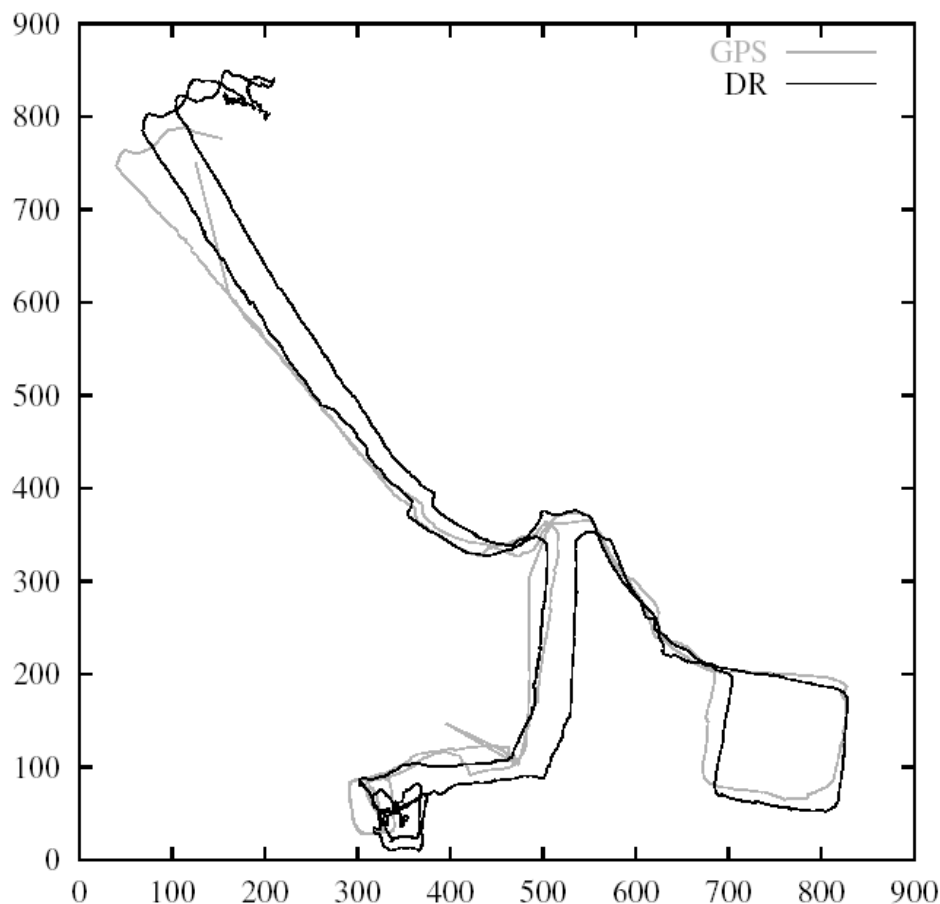


Figure 3.2 Positions developed by a DR system vs. GPS over a 4 km urban trail (from [14]).

⁴ Point Research Corporation was recently acquired by Honeywell.

The Dead Reckoning Module (DRM®) is a miniature, self-contained, electronic navigation unit that provides the user's position relative to an initialization point. The DRM® is the first commercially available practical implementation of a drift-free dead reckoning navigation system for use by personnel on foot. It is specifically designed to supplement GPS receivers during signal outages. You still know where personnel are located even when GPS is blocked by nearby buildings, heavy foliage, or even inside many structures. The DRM contains a tilt-compensated magnetic compass, electronic pedometer and barometric altimeter to provide a continuous deduced position. A microprocessor performs dead reckoning calculations and includes a Kalman filter to combine the dead reckoning data with GPS data when it is available. The filter and other proprietary algorithms use GPS data to calibrate dead reckoning sensors for a typical dead reckoning accuracy of 2% to 5% of distance traveled, entirely without GPS. Options for the system integrator include a selection of voltage input ranges, CMOS or RS232 interface, data logging, and special software functions. In addition to horizontal position data, compass azimuth, tilt (pitch and roll), and barometric altitude are available. [16]


For improved stability and accuracy, a version of the DRM can be obtained that includes a gyroscope. Figures 3.3 and 3.4, from [17] show an example of an improved DRM that uses a gyroscope.

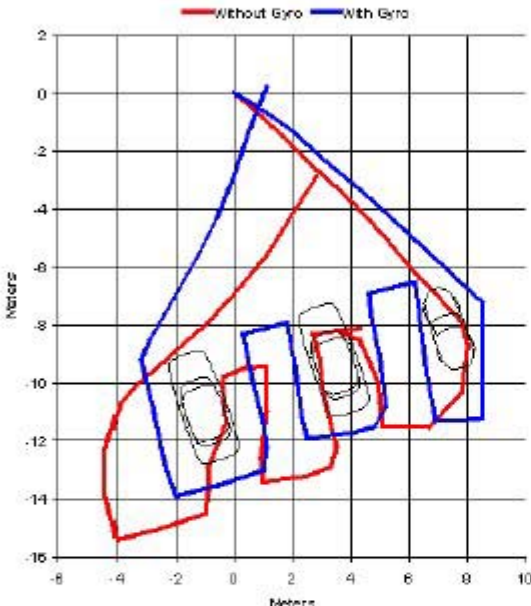
The relatively small size and cost of these personal navigation devices is made possible by the development in recent years of very small inertial and non-inertial sensors. For example, Micro-machined (MEMS) rate gyros based on vibration are available; a diagram of a semiconductor rate gyro based on a MEMS tuning fork is shown in Figure 3.5. The principle of a vibrating gyro is very simple: a vibrating object (such as a tuning fork) tends to keep vibrating in the same plane as its support is rotated. It is therefore much simpler and cheaper than is a conventional rotating gyroscope of similar accuracy. In the engineering literature, this type of device is also known as a *Coriolis vibratory gyro* because as the plane of oscillation is rotated, the response detected by the transducer (usually a piezoelectric device) results from the coriolis term in its equations of motion. [18]

There is some question as to whether the step-counting algorithms in current personal navigation devices are sufficiently sophisticated to adapt to the irregular stepping patterns of firefighters while doing their work. Even if they are not very accurate, it is possible that they are good enough to preserve a useful track if they are periodically updated by accurate position information (see below). For the purposes of this study, Division 892 has placed an order for the DRM described above and in Figures 3.3 and 3.4 so that it can be tested under various conditions relevant to first responder scenarios, and eventually integrated with an RFID reader for obtaining position fixes from RFID tags.

GyroDRM™ Gyro-Stabilized Dead Reckoning Module

Inertially aided dead reckoning navigation for personnel on foot





- Robust personnel navigation
- Navigate without GPS
- Errors 1 to 5 meters per 100 meters
- Gyro-stabilized version of DRM®-III
- No infrastructure required
- 12-channel civilian GPS receiver
- Data recording capability
- Event marker
- Barometric altimeter
- SmartPedometry™ algorithms
- Composite dead reckoning + GPS
- Magnetic anomaly alarm

GyroDRM™ provides reliable, self-contained position data for personnel on foot when navigating in areas where Global Positioning System (GPS) signals are difficult to receive. Advanced silicon gyro technology combined with Point Research's proven DRM®-III provides significantly reduced effects of magnetic disturbances on position accuracy. The GyroDRM™ is provided as an integrated unit, complete with GPS receiver, lithium ion-polymer battery, data recording memory and event marker. This unit can be used in a stand-alone mode without a host computer to record the

position and direction of the person to which it is attached. Recording intervals of up to 24 hours are feasible. Improved algorithms provide discrimination for backward and lateral motion, as well as ignoring a person's "fidgeting" motions. The unit is designed to self-calibrate when GPS is available. The World Magnetic Model is built-in so that the integral magnetic compass can automatically provide azimuth referenced to true north. A magnetic anomaly alarm can be used to detect persistent magnetic disturbances at a user-defined level.

Point Research CORPORATION

17150 Newhope Street, Suite 709, Fountain Valley, California 92708
 (714) 557-6180 FAX (714) 557-5175 www.pointresearch.com

Applications

- Military
- RF field mapping
- Public safety
- Urban mapping
- Security guards
- Forestry
- GIS

Figure 3.3 Manufacturer's brochure for gyro-stabilized dead reckoning module, page 1.

GyroDRM™ Gyro-Stabilized Dead Reckoning Module

SPECIFICATIONS

Parameter	Value
Dead reckoning relative position accuracy	1 to 5 meters per 100 m without GPS fix (1% to 5% distance traveled)
Barometric altimeter accuracy	1.5 meters, 1 meter resolution
Azimuth accuracy	1° RMS
Angular rate range	±573°/second
GPS receiver	12-channel SPS
Housing size	4.4" x 3.2" x 1.5"
Weight	12 ounces
Temperature range	0° to +70° C
Power, average	0.6 watts
Battery	8.4v Li-Ion Polymer
Data refresh rate	Up to 4Hz
Serial data interface	RS-232C levels, 9.6K-38.4 K b/s
Connector	DB-9

FEATURES

Data Logging Memory

- 32K records, user defined sample interval
- ASCII download to personal computer

Interface Protocol

- Point Research binary, bi-directional
- NMEA0183, 9600 b/s, RMC sentence

Software Features

- Kalman filter blended GPS/dead reckoning
- World Magnetic Model for true azimuth
- Metabolic expenditure (calories)
- Body orientation, prone, upright, etc.
- Field upgradable firmware
- Provision for external position fixes
- User definable power-up defaults

GPS Receiver

- 12-channel, L1, SiRFstar1
- 5 meters CEP accuracy, S/A off
- Power management modes
- Coin cell memory battery backup
- Active patch antenna

ENGINEERING EVALUATION KIT

- GyroDRM™ with battery (A) in plastic housing with belt clip.
- Windows® host test program (B) with data recording and graphic data display. Programmer / User manual includes binary protocol definition
- GPS active antenna (C)
- Computer interface (D), RS232 DB-9 serial
- Event marker switch (E)
- AC power adapter (F)
- Li-ion battery charger (G)
- Baseball cap with hook & loop for GPS antenna
- Technical support via phone or email

U.S. Patent No. 5,583,776 and other patents pending
 DRM is a registered trademark of Point Research Corporation.
 GyroDRM is a trademark of Point Research Corporation.
 Specifications and features subject to change without notice.
 Revision of September 2004.



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CORPORATION

17150 Newhope Street, Suite 709, Fountain Valley, California 92708
 (714) 557-6180 FAX (714) 557-5175 www.pointresearch.com

Figure 3.4 Manufacturer's brochure for gyro-stabilized dead reckoning module, page 2.

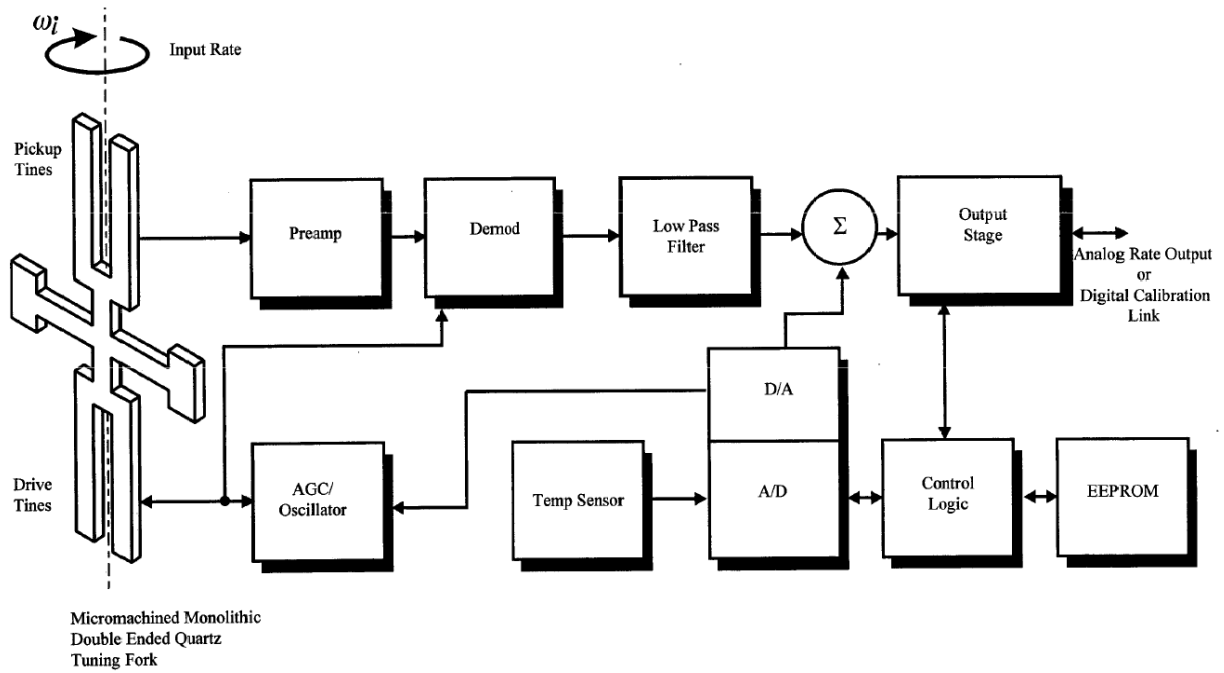


Figure 3.5 Block diagram of a semiconductor gyro based on MEMS technology (from [19]).

4. FY 2005 Milestone C: Number and Placement of Tags

4.1 Scope of Tasks

4.1.1 Restatement of Milestone C

Analyze the requirements for the number of RFID tags and their placement to achieve desired localization accuracies, as a function of navigation techniques and device options.

4.1.2 Scope

- This milestone is predicated on the results of milestones A and B in that it assumes respectively that a required localization accuracy or range of accuracies has been stated and that the accuracies of various navigation techniques have been formulated in terms of the spatial density of waypoints and/or frequency of navigation fixes.
- The analysis in this milestone does not explicitly consider the uncertainty in the position fix provided by an RFID tag/reader combination; if possible, an error term for waypoints or fixes should be included in the analysis.

4.2 Progress and Findings

4.2.1 Summary of Progress

Although general information on the accuracy of potential navigation techniques for use indoors was developed, it was realized during the project that it was premature to analyze the final accuracy of an RFID-assisted inertial system at this time.

One factor involved is that the accuracy of the dead reckoning module to be tested is unknown under the conditions to be expected in a first responder scenario, particularly the effect of irregular walking on the step-counting algorithm.

Another factor involved is that there is no device available to first responders at this time that provides indoor location with any reliable degree of accuracy—the firefighting community would consider the ability just to identify the floor of the building on which a firefighter is located would be a step forward. Therefore, it is not appropriate to focus on analysis of the potential accuracy of a sophisticated system yet.

However, the project team did agree that it would be useful to begin to evaluate the requirements for placement of RFID tags in order to indicate location from the tags alone.

4.2.2 Summary of Findings

Using just RFID tags to derive the indoor location of a first responder has certain advantages that are known in advance. The “you are here” event of detecting a particular RFID tag in a building provides a positive indication of not only which floor of the building the first responder is on, but also which room/work area he or she is nearest to, assuming the ability to correlate the data on

the RFID tag with building information or the existence of this information on the tag itself. That is, this result can be expected if there is no ambiguity in the case of the detection of more than one RFID tag.

In the industrial and supply chain applications of RFID technology, the expectation is that many tags will be within the range of the RFID reader, so that the standards for RFID devices provide protocols and procedures for resolving the signals from multiple tags. However, no attempt is made to determine the locations of the multiple tags, other than that they are all within the range of the reader.

Since the “read range” of RFID tags is very dependent on the specific RFID technology that is being used, some RFID tags and readers were procured and testing was performed to determine the read range and related parameters.

5. FY 2005 Milestone D: Options for RFID Technologies

5.1 Scope of Tasks

5.1.1 Restatement of Milestone D

Evaluate options for RFID technologies—including both tags and readers—to use for location updating of a navigation system implemented on a small, battery-powered device similar to a handheld computer or PDA (personal digital assistant).

5.1.2 Scope

- The RFID technologies referred to in this milestone include not only the currently available devices, standards, and frequencies, but also any technique by which a person in a building can automatically detect that he is in a known location.
- Discovery of a technique for deducing the orientation of a person at the time of detecting a device in a known location would be significant information for the study.
- For system studies, the evaluation of RFID technologies should include availability, cost, portability, and power consumption in addition to the functional parameters of read range and data capability.

5.2 Progress and Findings

5.2.1 Summary of Progress

We have established a test bed for estimating read range as a function of power. Due to issues of availability of development kits, these tests have largely been performed at 13.56 MHz. However, we believe that the 400–450 MHz and the 900–930 MHz bands offer more promise in achieving the read ranges desired using passive tags. Since battery lifetimes for active tags are of the order of 5 years, passive tags are to be preferred for this application.

5.2.2 Summary of Findings

NIST-Boulder has developed an RFID test bed at 13.56 MHz that complies with the ISO 14443 and 10373-6 standards. We have evaluated the 13.56 MHz passive tags. The tags and readers communicate via magnetic coupling which limits the read range to less than 10 cm for typical readers (simple loop antenna). More complex loop systems can be used to extend this range, as shown in Figure 5, but the practicality of such systems for first responder navigation remains under investigation. The key challenge is that because of the large wavelength of approximately 22 m, these systems operate in the near field with the magnetic field strength dropping as one over the distance cubed.

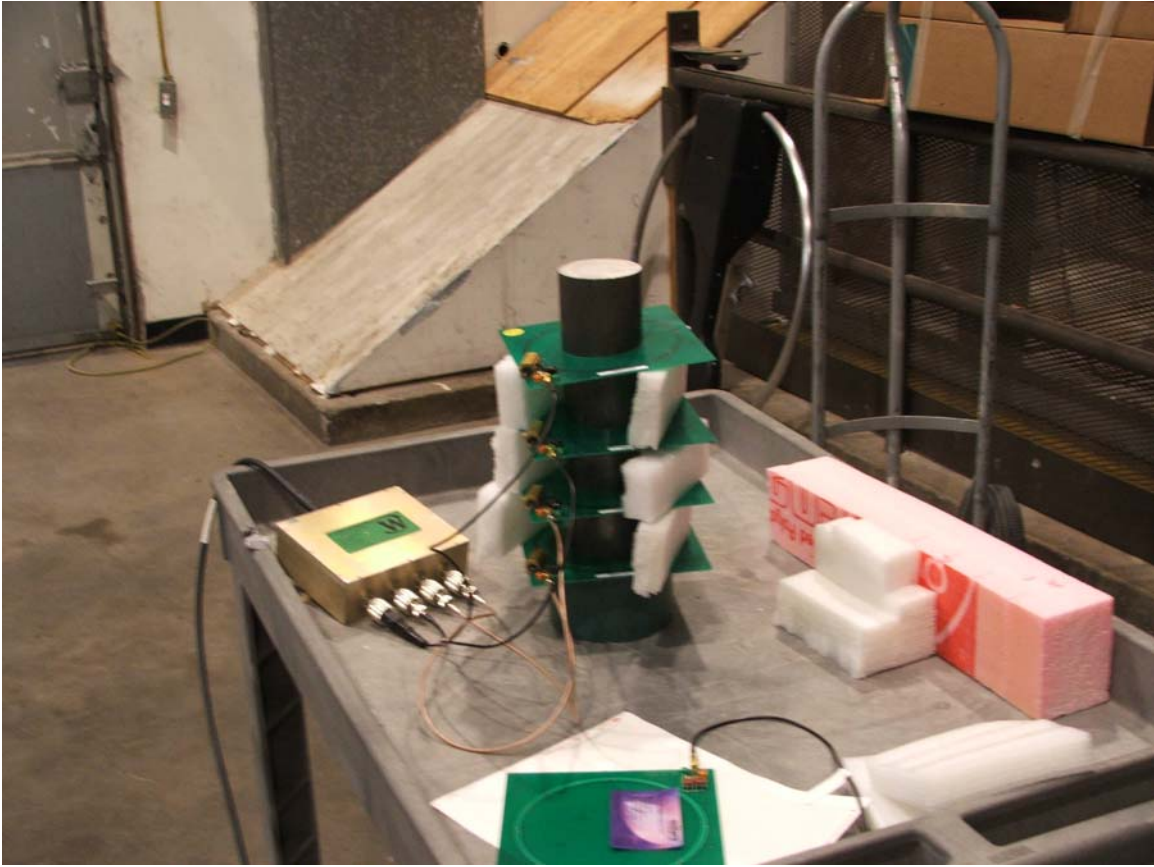


Figure 5.1 Stacked 15 cm PCD loops used for magnetic field range and tag activation.

For higher frequencies, such as 400 MHz and 900 MHz, wavelengths are about 0.3 – 0.8 m. These systems operate in the far field. Coupling is via the electric field and the field drops more slowly (as one over the distance). This results in an anticipated read range of several meters for passive tags. It has been noted [21] that 600 MHz – 2 GHz is the best frequency band for propagation in buildings.

We have also started to evaluate an active tag RFID system that operates at 433 MHz, shown in Figure 5.2. This system requires an additional computer and power supply. The tags are battery powered. The tag and reader communicate using an electric field and the read range is over 30 meters. The reader can be set to recognize the tag responding with most power. This should be the tag closest to the first responder unless the battery power is low.

We have ordered 900 MHz RFID systems with software development kits. Anticipated delivery is mid-November 2005. These are passive tag systems. One uses a hand held reader that weighs only 1 kg and has a read range of approximately 3 meters (see Figure 5.3).

There is on-going work in the industry to optimize the performance and reduce the costs of RFID antennas and readers [22–26].

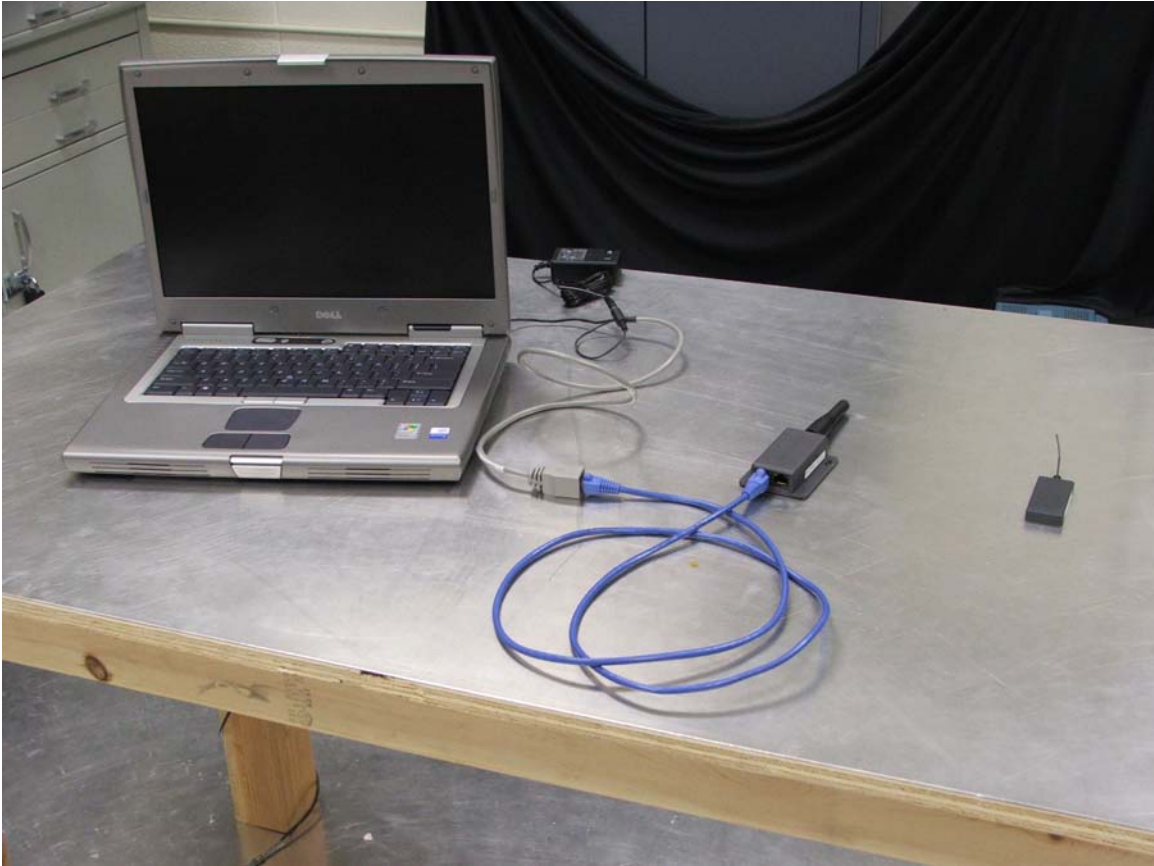


Figure 5.2 RFID system using active tags at 433 MHz.



Figure 5.3 Handheld 900 MHz reader.

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Appendix: Project Web Page

http://www.antd.nist.gov/wctg/RFID/RFIDassist.htm

RFID-Assisted Localization and Communication...

Advanced Network Technologies Division
RFID-Assisted Localization & Communication for 1st Responders
NIST National Institute of Standards and Technology

WCTG Home **WCTG Projects** **WCTG People** **ANTD Home** **ITL Home**

This page updated 9/27/05 by LMiller at ANTND dot NIST dot GOV

The RFID-Assisted Localization and Communication for First Responders project will determine the feasibility of using RFID-assisted localization in combination with an ad-hoc wireless communication network to provide reliable tracking of first responders in stressed indoor RF environments, where GPS-based localization and links to external communication systems are known to be unreliable. The research will also consider the means and potential for embedding critical building/occupant information in specific on-site RFID tags to enhance the safety and efficiency of the first responders' mission as well as to minimize dependence upon communication with external building databases.

[Related Links](#)
[Project Staff](#)
[Project Resources--Links](#)
[Project Resources--Bibliography](#)
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Related Links:
[Public Safety Wireless Technology Links](#)
[NIST Communications and Networking for Public Safety project page](#)

Principal Investigators:

Leonard E. Miller	Perry F. Wilson	Nelson P. Bryner
ITL/ANTD	EEEL/EMD	BFRL/FRD
301-975-8018	303-497-3406	301-975-6868

Contributing Members:

Luke Klein-Berndt	Michael H. Francis	Jeffrey R. Guerrieri	David W. Stroup
ITL/ANTD	EEEL/EMD	EEEL/EMD	BFRL/FRD
301-975-8029	303-497-5873	303-497-3863	301-975-6564

PROJECT RESOURCES--Links

Building info, location coordinates, etc.
[Stairway identification](#) (Arlington, VA building code)

Communication systems for ad hoc indoor scenarios
[Ascentry](#) 802.11b mesh network "breadcrumbs"
[Cirronet](#) Zigbee modules and terminals
[Crossbow wireless sensor networks](#)
[Dust Networks](#) mesh networks for sensors
[Ember](#) Zigbee solutions
[Helicom](#) Zigbee development tools
[Kiyon](#) wireless networking of RFID readers
[MANTIS](#) project at U. Colorado
[MaxStream](#) Zigbee development kits

Localization, navigation technology for possible indoor use
[Compass basics](#)
[Dynastream](#) Speedmax inertial sensor technology
[Elpas](#) local positioning systems
[Eyeglass](#) local positioning system
[Findability](#) links
[Fugawi](#) navigation software
[Global Locate](#) indoor GPS solutions
[John Heidemann](#) papers on localization and sensor networks
[Indoor and pedestrian navigation](#) presentation
[Indoor and pedestrian navigation](#) working group of IAG
[Indoor GPS](#) products
[Information Systems Laboratory](#) wireless firefighter lifeline
[JAZZ](#) wayfinding and auto-routing

[MicroStrain](#) orientation sensor
[NAVIO](#) indoor/outdoor personal navigation research project
[On Target Software Solutions](#) inertial measurement systems
[Place Lab](#) location using Wi-Fi
[Point Research](#) dead-reckoning sensors for personal and vehicle navigation
[RFID Radar](#) concept from Trolley Scan Ltd
[Rotomotion](#) inertial navigation modules
[Stack](#) A modular platform for high density wireless sensing
[Systron Donner](#) MotionPak inertial sensing system
[Vectronix](#) miniature digital magnetic compass
[Vectronix](#) personal navigation module
[Xsens](#) miniature inertial motion sensors

RFID technology links that may be useful

[ACG](#) Compact Flash RFID reader
[ActiveWave](#) RFID readers
[AIM Global](#)
[Applied Wireless](#) RFID tags and readers (including PCMCIA card readers)
[Dynasys](#) RFID superstore
[Ember Corporation](#) -- embedded wireless networking devices
[Emergent Technology](#) vehicle tracking
[EPCglobal](#)
[Escort](#) high temperature UHF tags
[Hermes](#) PCMCIA card RFID reader
[HID](#) cards and readers
[High Tech AID](#) resources about RFID
[Intermec](#) portable RFID reader/writers
[LXE](#) handheld computers and RFID readers
[One Source](#) PDA RFID Reader/Writers
[Precision Dynamics](#) RFID wristband systems
[Randall's RFID Page](#)
[RFIDa](#) news, information
[RF-ID.com](#) Compact Flash RFID reader
[RFID Inc.](#) RFID hardware
[RFID Journal](#)
[RFID News and Solutions](#)
[The RFID Reader](#)
[RFID Times](#) blog
[rfidXchange](#)
[Savi](#) RFID networking solutions
[Security of RFID](#) test case
[Sirit](#) vehicle ID systems
[SkyeTech](#) miniature RFID reader
[Symbol Technologies](#) RFID products
[Tectus](#) RFID components
[Tek](#) RFID adapter for PDA
[ThingMagic](#) agile RFID readers
[TI-RFID](#)
[Article](#) on low-cost readers from Toppan
[Transponder News](#)
[Using RFID](#) news
[WJ Communications](#) RFID reader PCMCIA cards

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RFID technology that may be useful

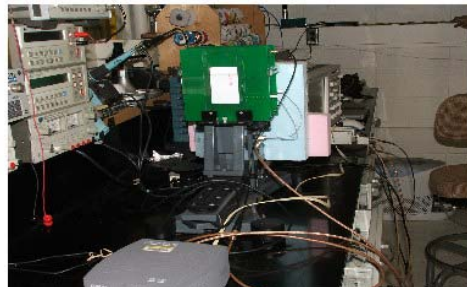
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PHOTO GALLERY from our lab in Boulder



RFID field testing apparatus for ISO 14443 and 10373 standards.

Load Modulation Testing.





Resonant frequency testing.



Contactless RFID testing and analysis setup.



Contactless RFID testing and analysis setup (closeup).